The Vulnerable: How Race, Age and Poverty Contribute to Tornado Casualties

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Who Survives?

Credit: Dayton Daily News

Take-Home Points

- A 10 **mobile home** increase under the path **increases** the casualty rate by 4.2%
- A 100 person increase in the population **over 65** under the path **increases** the casualty rate by 1.4%
- A percentage increase in the **white** population under the path **decreases** the casualty rate by 25%

Objectives

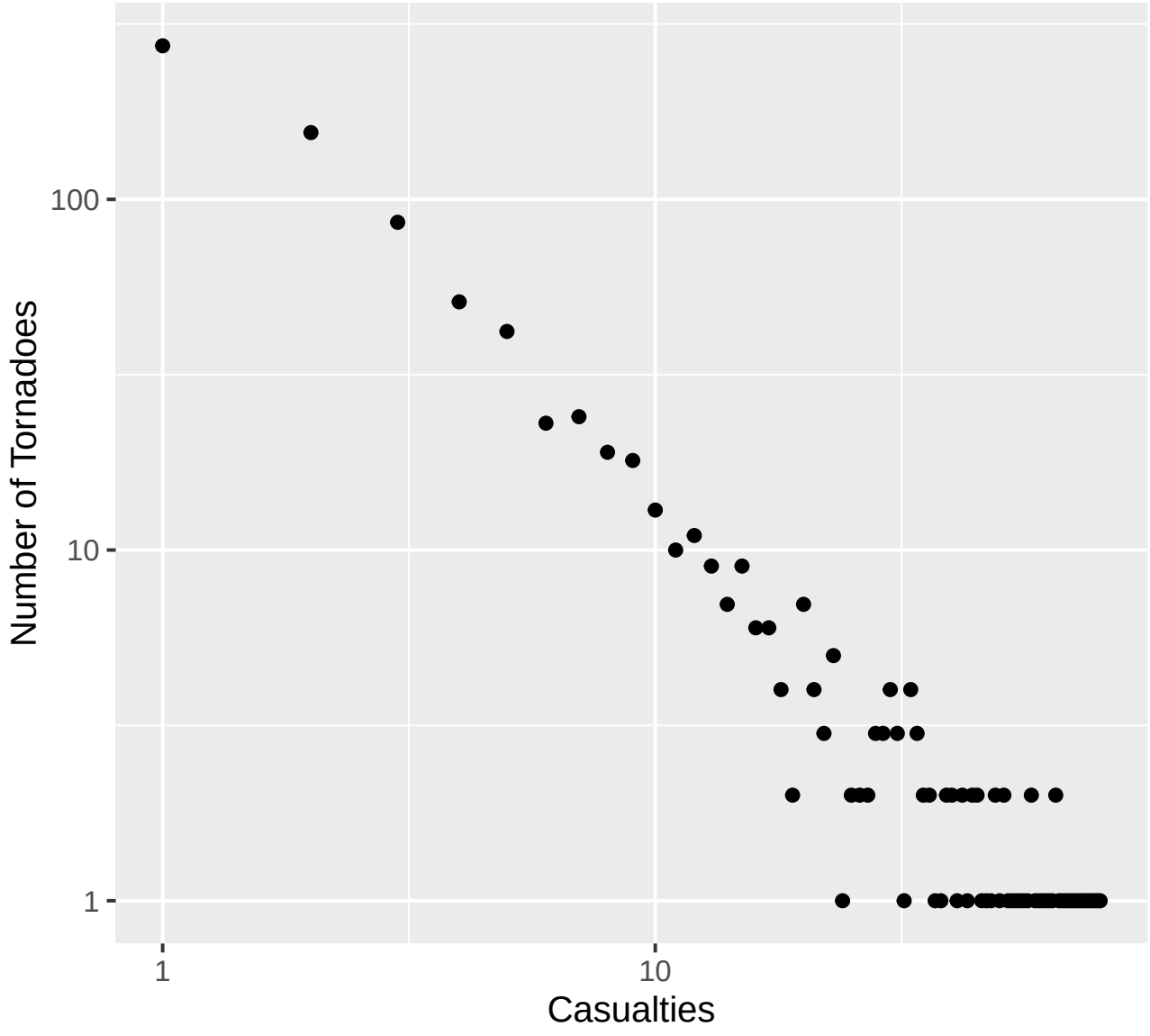
- Establish statistical estimates (and margins of error) on how sensitive casualties are to:
  - Changes in population and,
  - Changes in tornado strength
- Examine these sensitivities across space

Casualty-Producing Tornadoes

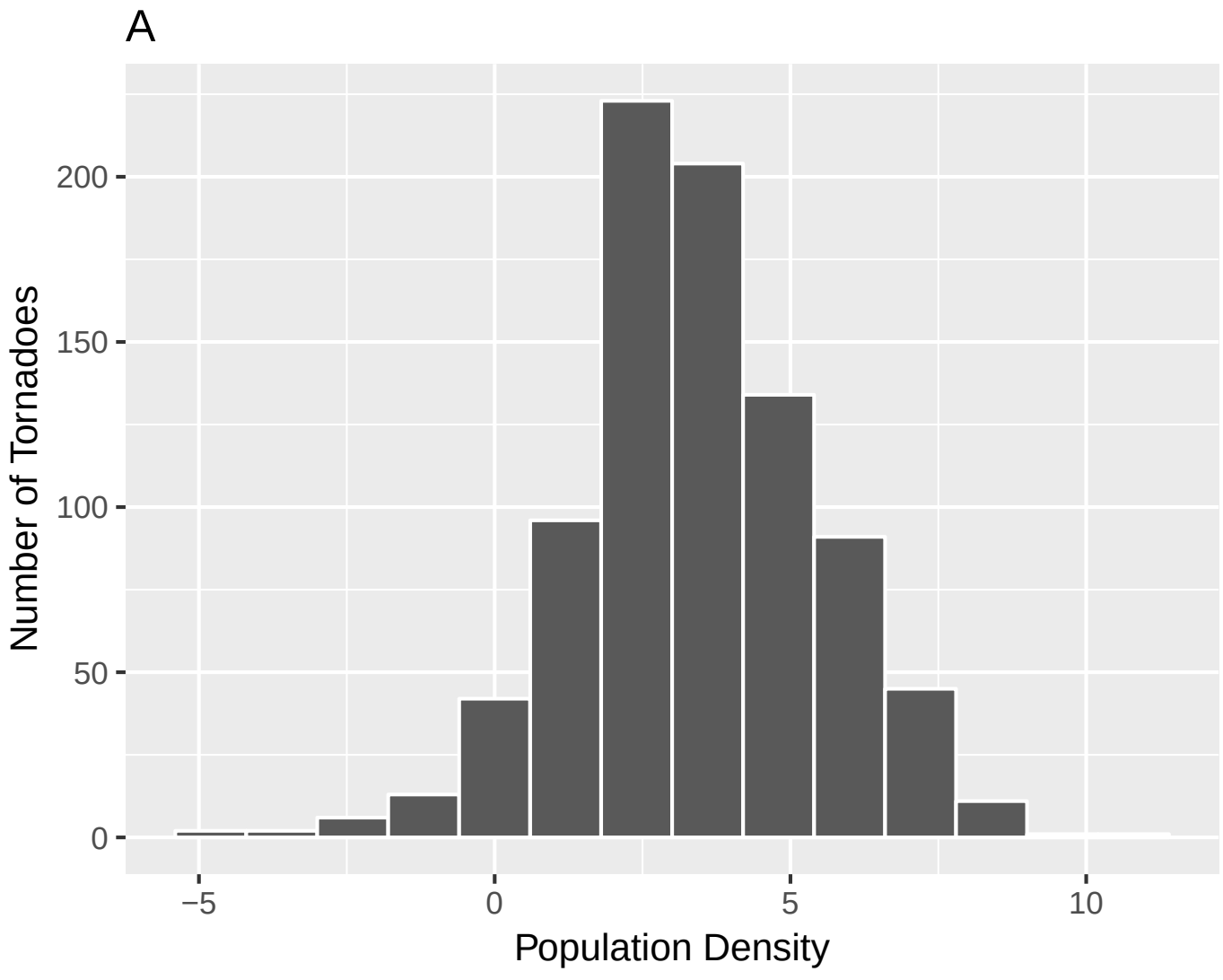
NATIONAL TORNADO SUMMIT & DISASTER SYMPOSIUM

Tornado Paths

Casualties



Population Density



Energy Dissipation

The equation for energy dissipation is

$$E = A_p \rho \sum_{j=0}^{J} w_j v_j^3, \tag{1}$$

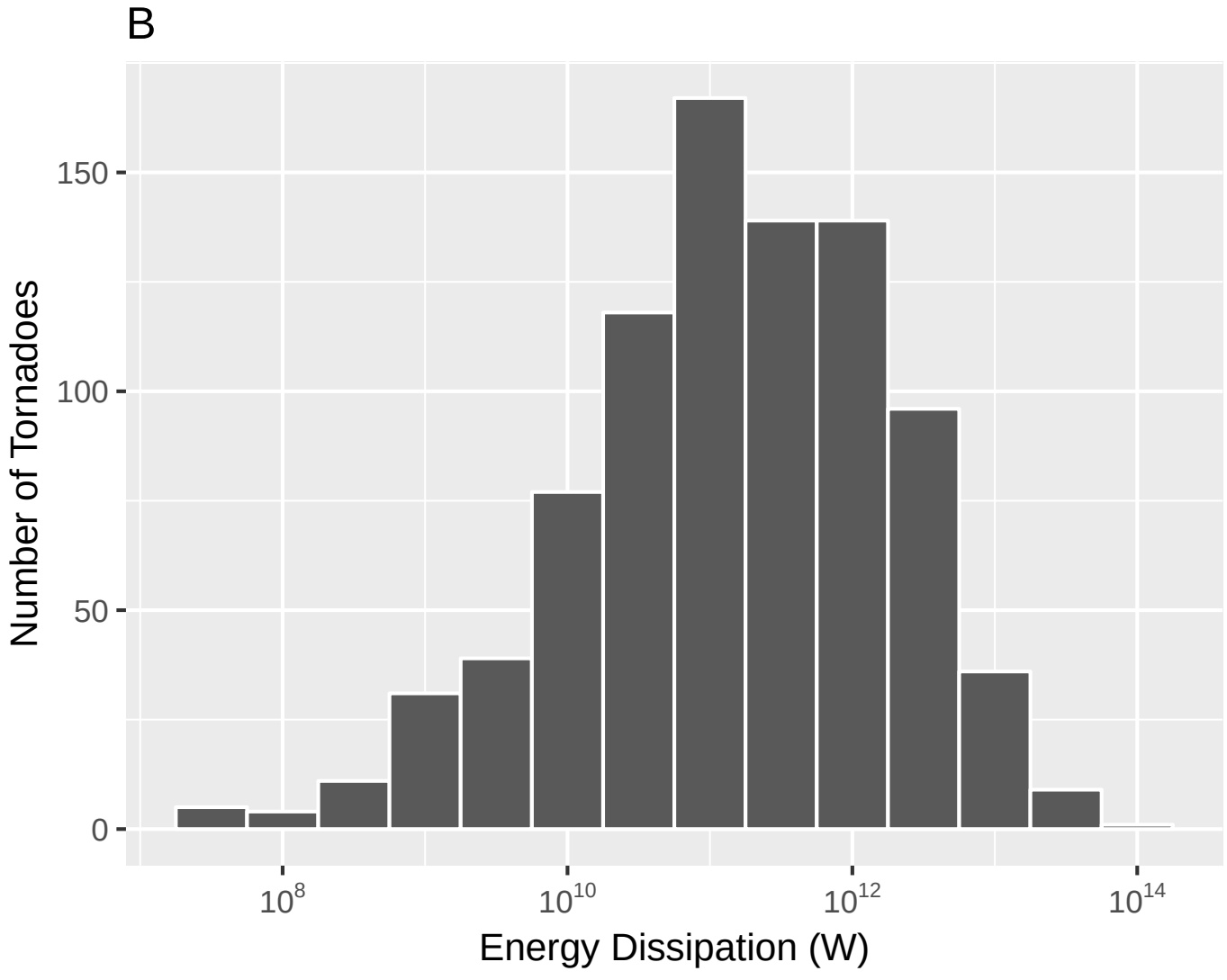
where A_p is the area of the approximate path (width times length), ρ is the air density (assumed to be 1 kg/m^3 at the surface), v_j is the midpoint wind speed for each damage rating j, and w_j is the corresponding fraction of path area.

Schematic of Path Area

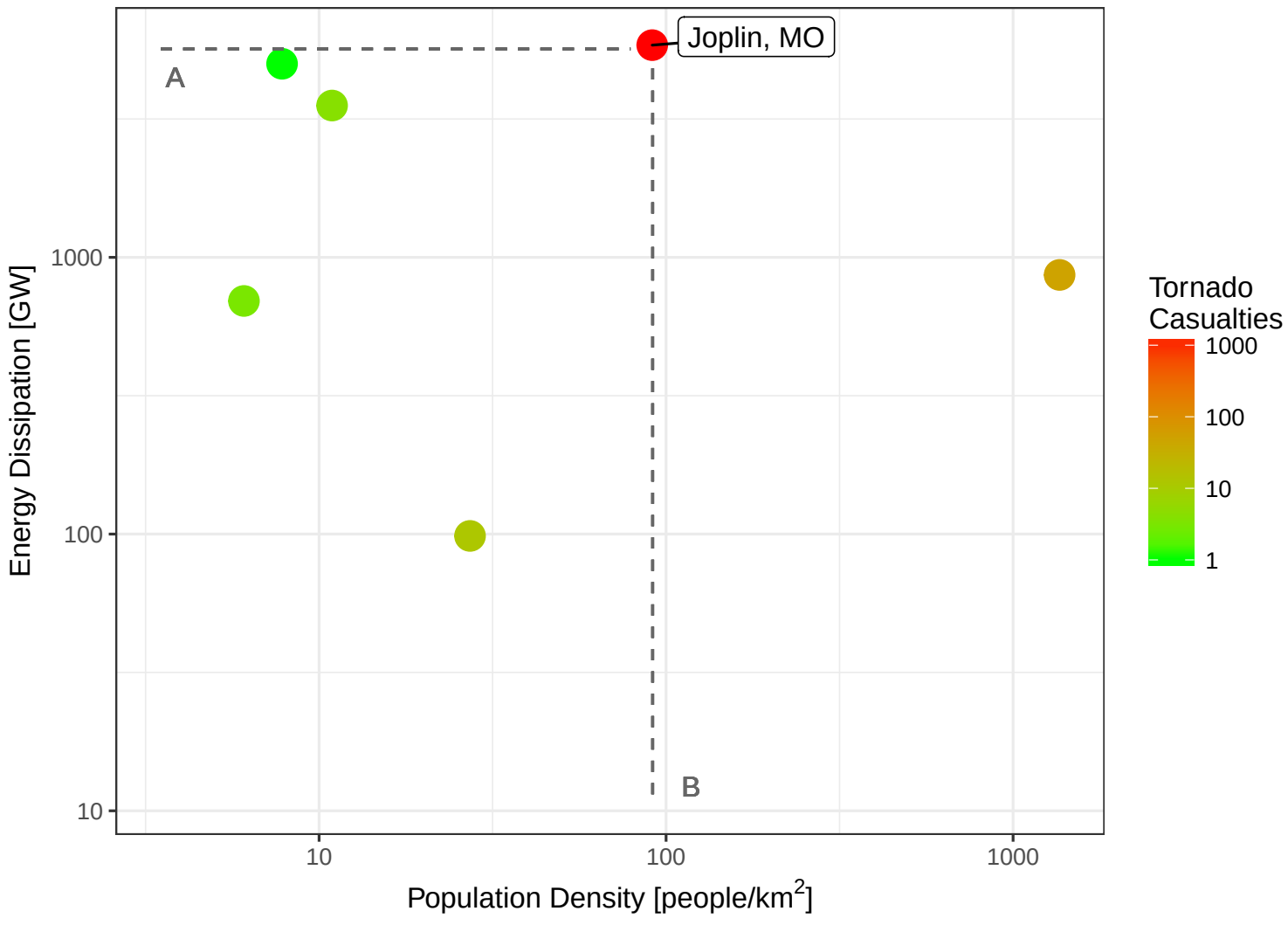
Percent of Path Area by EF Rating

	Wind Speed	Maximum EF rating (w_j)					
	[m s^{-1}]	EF0	EF1	EF2	EF3	EF4	EF5
EF0	29–38	1	0.772	0.616	0.529	0.543	0.538
EF1	38–49		0.228	0.268	0.271	0.238	0.223
EF2	49–60			0.115	0.133	0.131	0.119
EF3	60–74				0.067	0.056	0.070
EF4	74–89					0.032	0.033
EF5	89						0.017

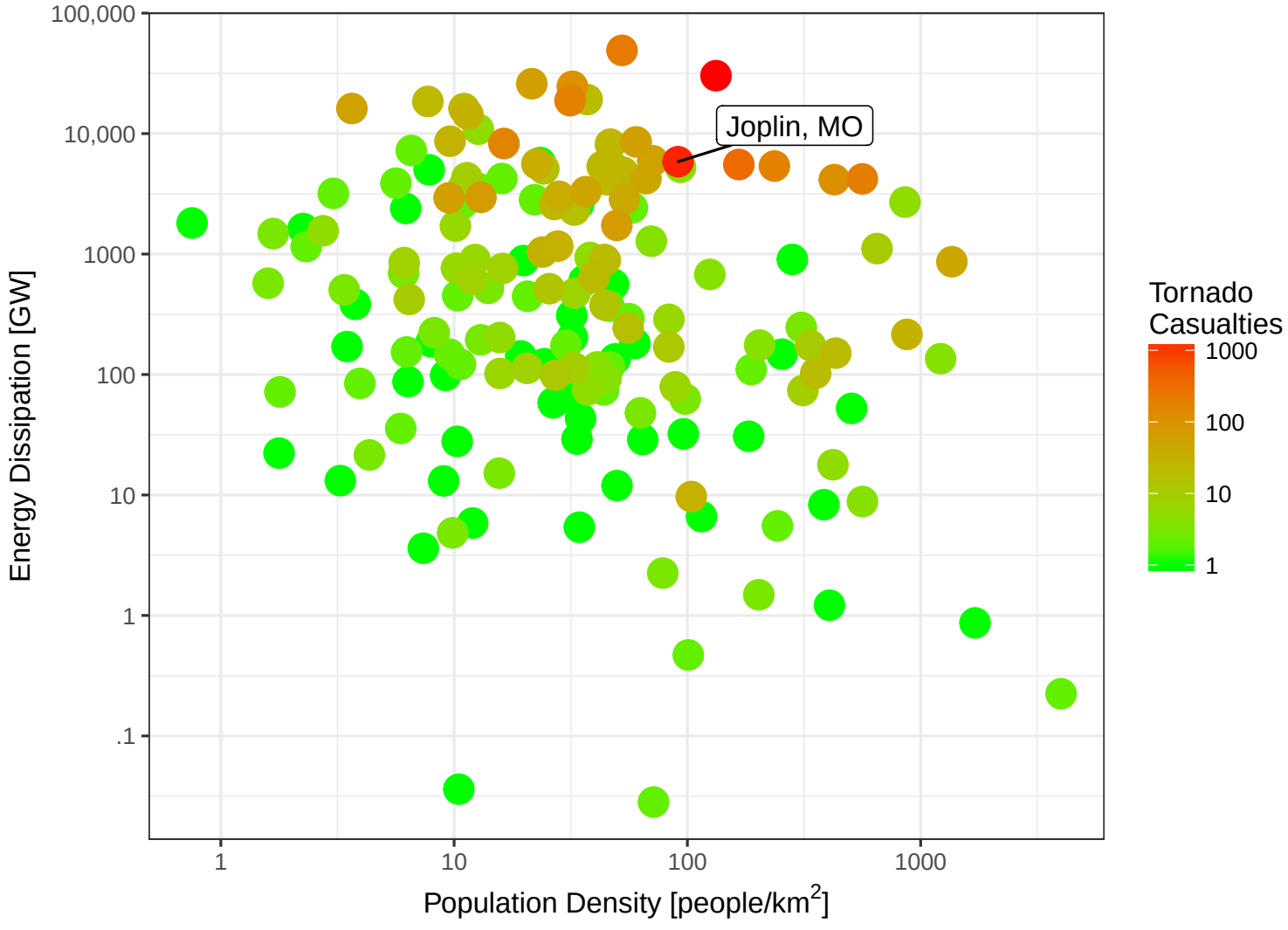
Energy Dissipation



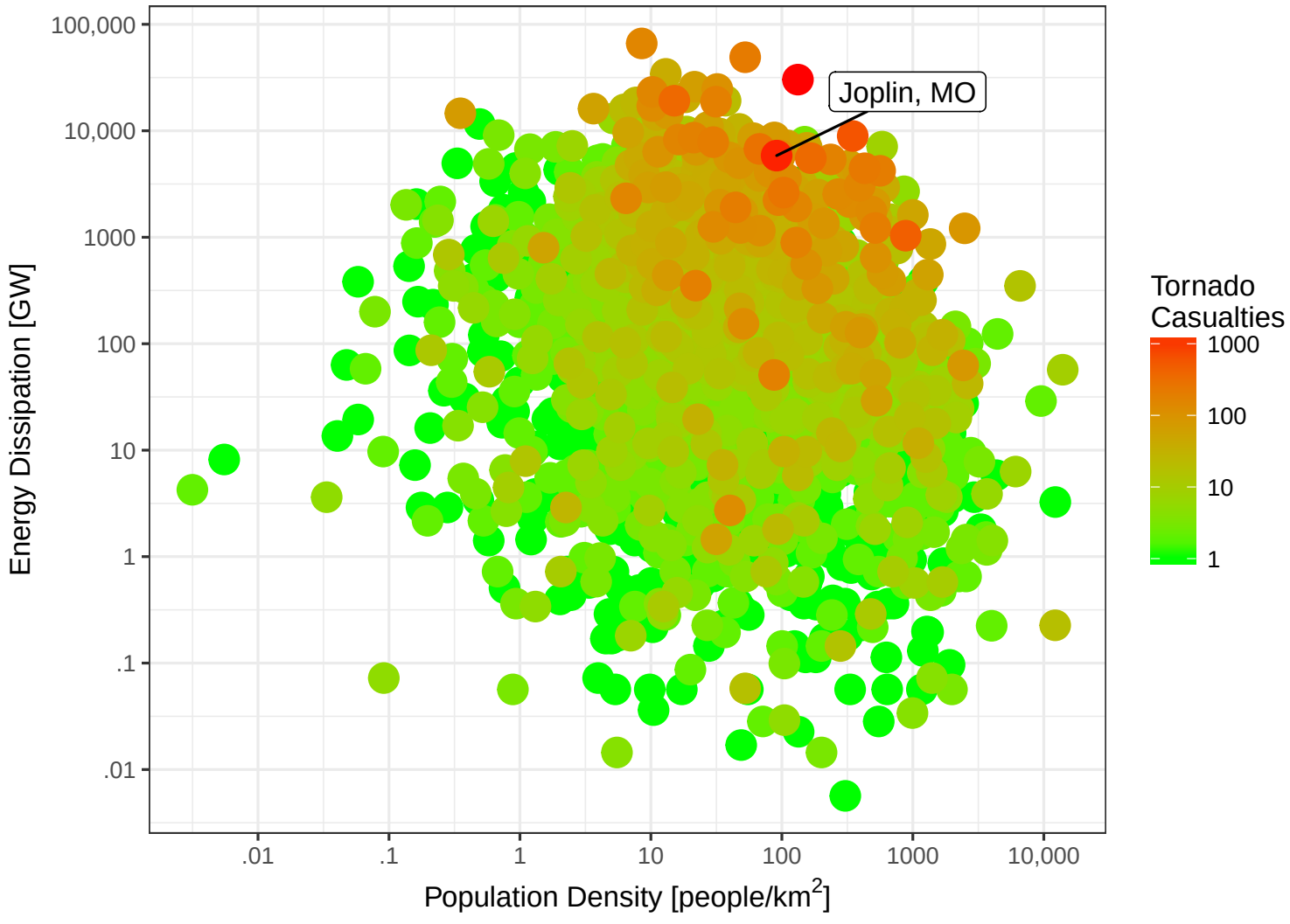
May 22, 2011 Casualty-Producing Tornadoes



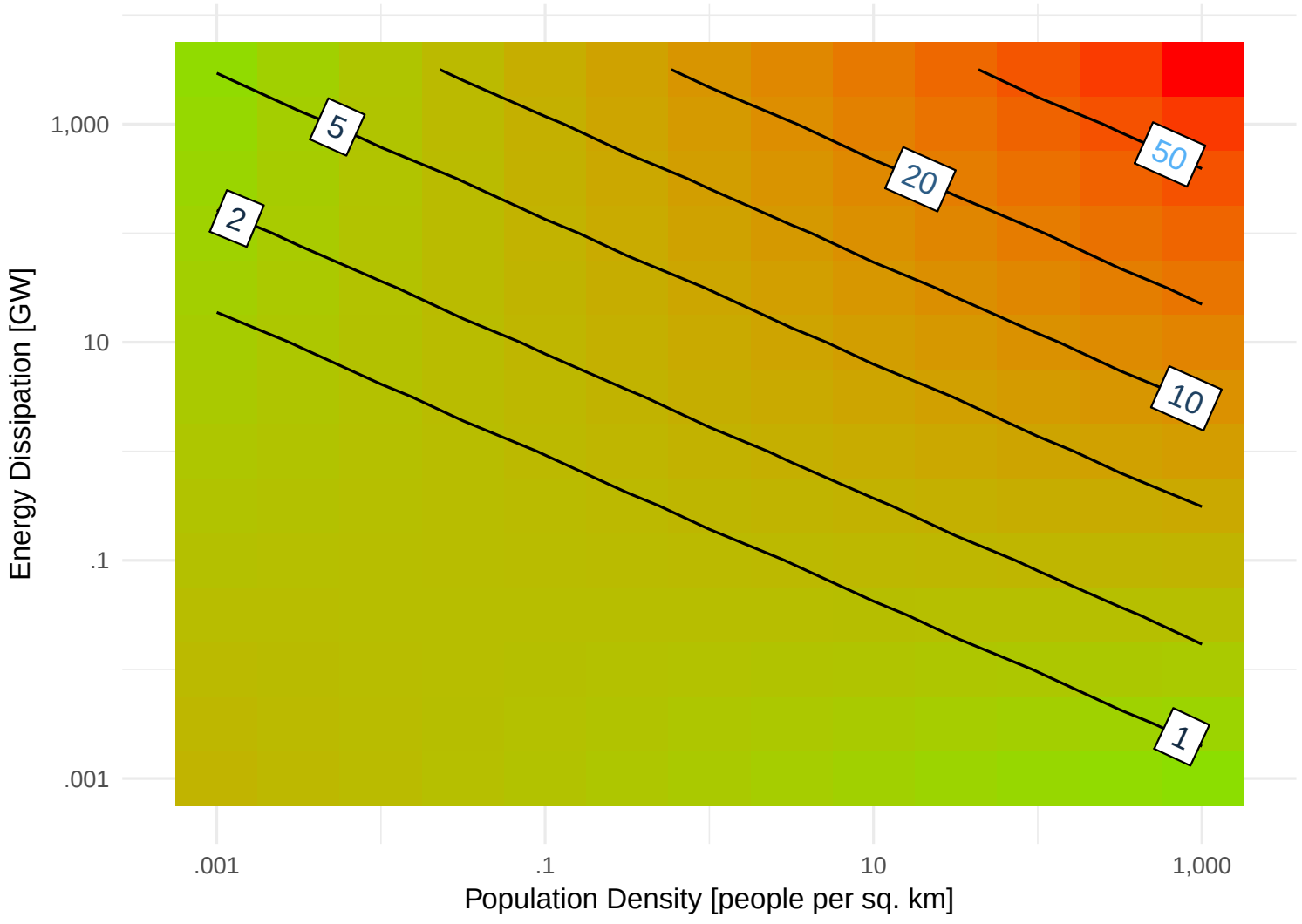
2011 Casualty-Producing Tornadoes



All Casualty-Producing Tornadoes



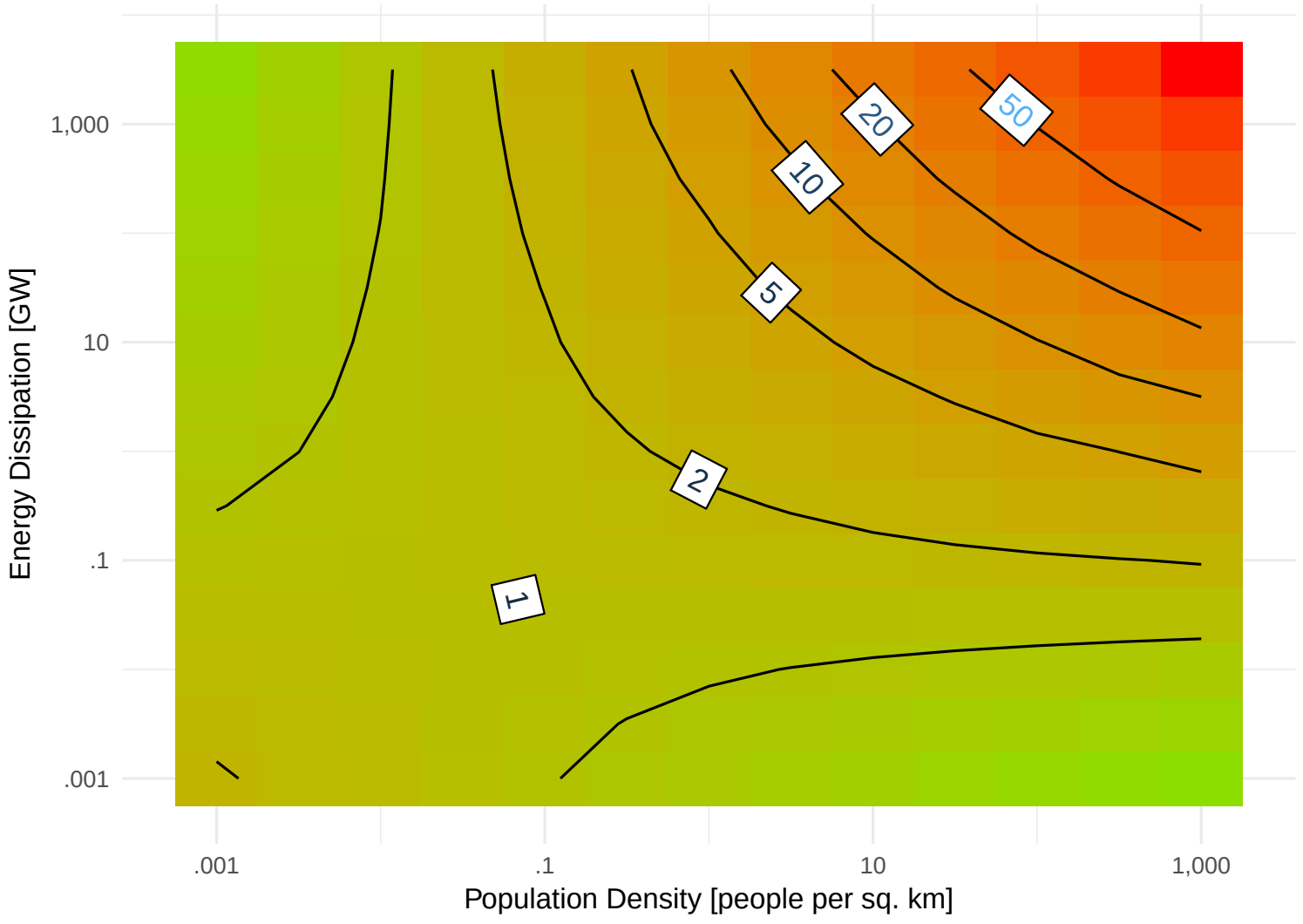
Additive Model



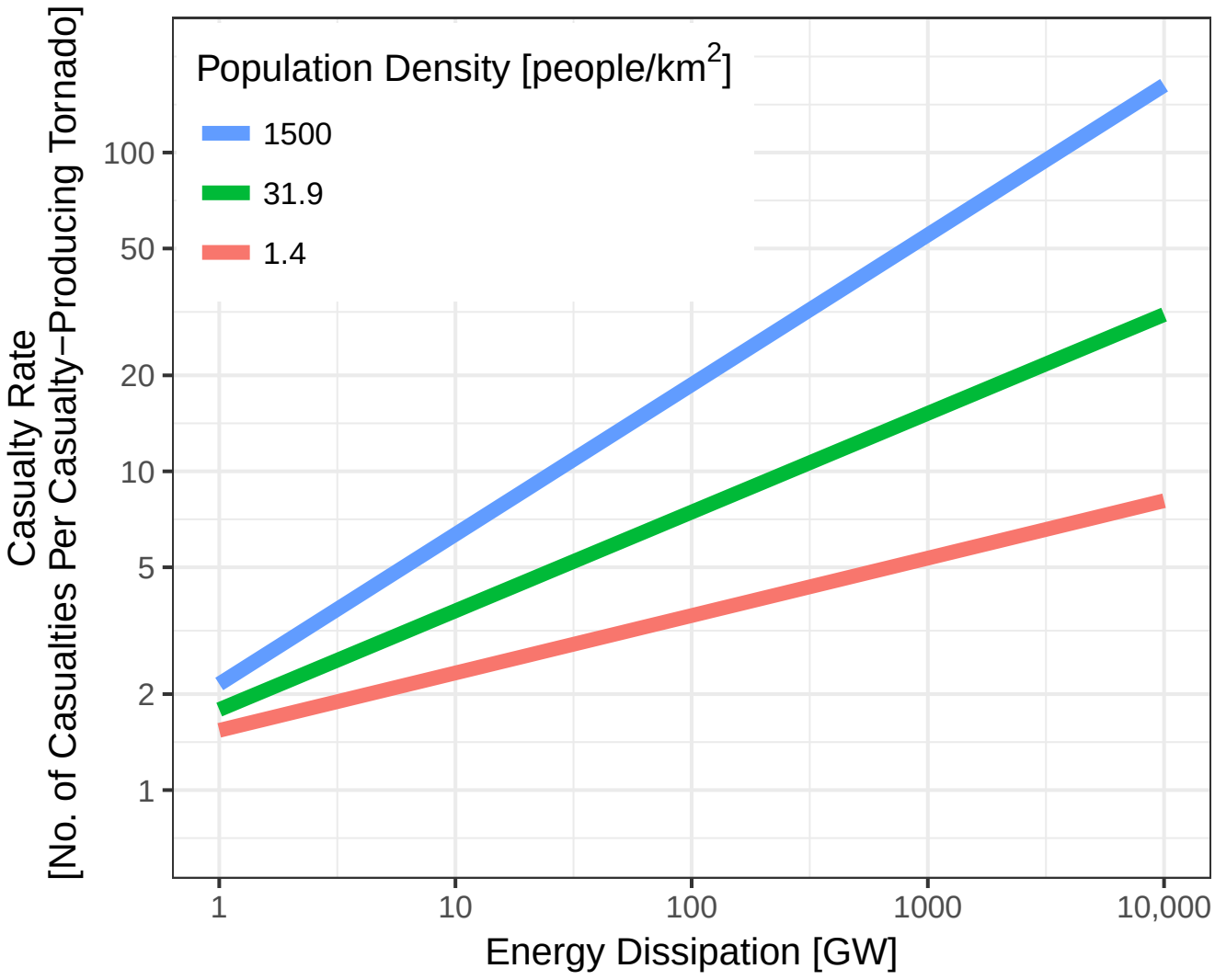
Additive Model Results

- A doubling of the population under the path of a tornado leads to a 21% increase in the casualty rate
- A doubling of the energy dissipated by the tornado leads to a 33% increase in the casualty rate

Interactive Model



Casualty Rates



Interactive Model Results

- The percentage increase in casualties with increasing energy dissipation *increases* with population density
- The percentage increase in casualties with increasing population density *increases* with energy dissipation

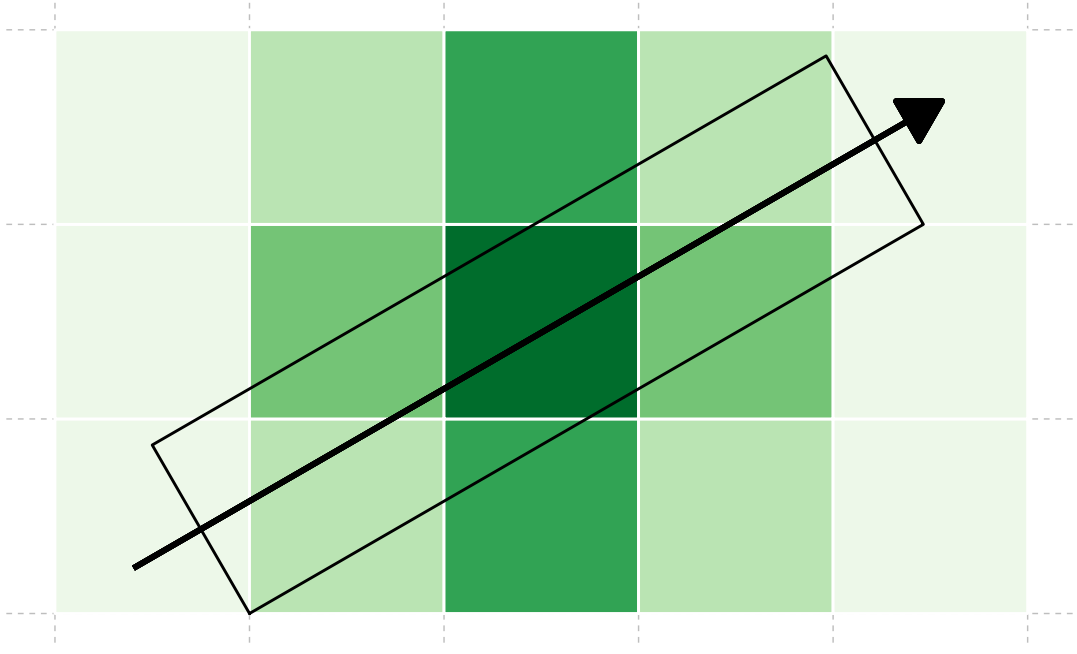
Slopes by State

Rank	State	Magnitude of Slope
1	Arkansas	1.023
2	Tennessee	0.717
3	Missouri	0.607
4	Kentucky	0.493
5	Illinois	0.417
6	Oklahoma	0.404
7	Alabama	0.347
8	Mississippi	0.329
9	Texas	0.308
10	North Carolina	0.286
11	Louisiana	0.246
12	Georgia	0.128

Drilling-Down

- Establish estimates of socioeconomic and demographic variables at the tornado level
- Evaluate the relationship of socioeconomic and demographic variables between:
  - Individual tornadoes
  - Damage characteristic (e.g. casualties)

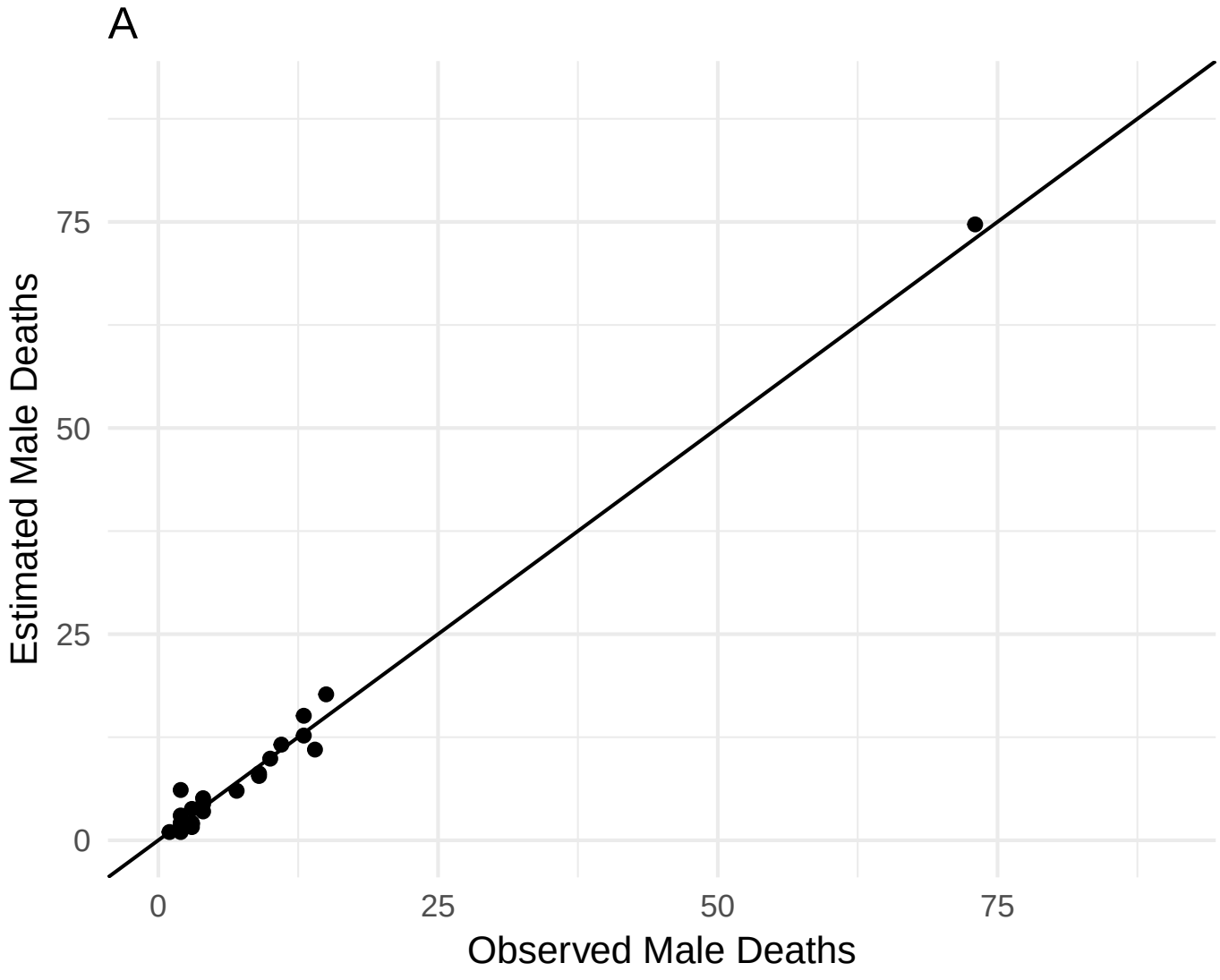
Overlay Method



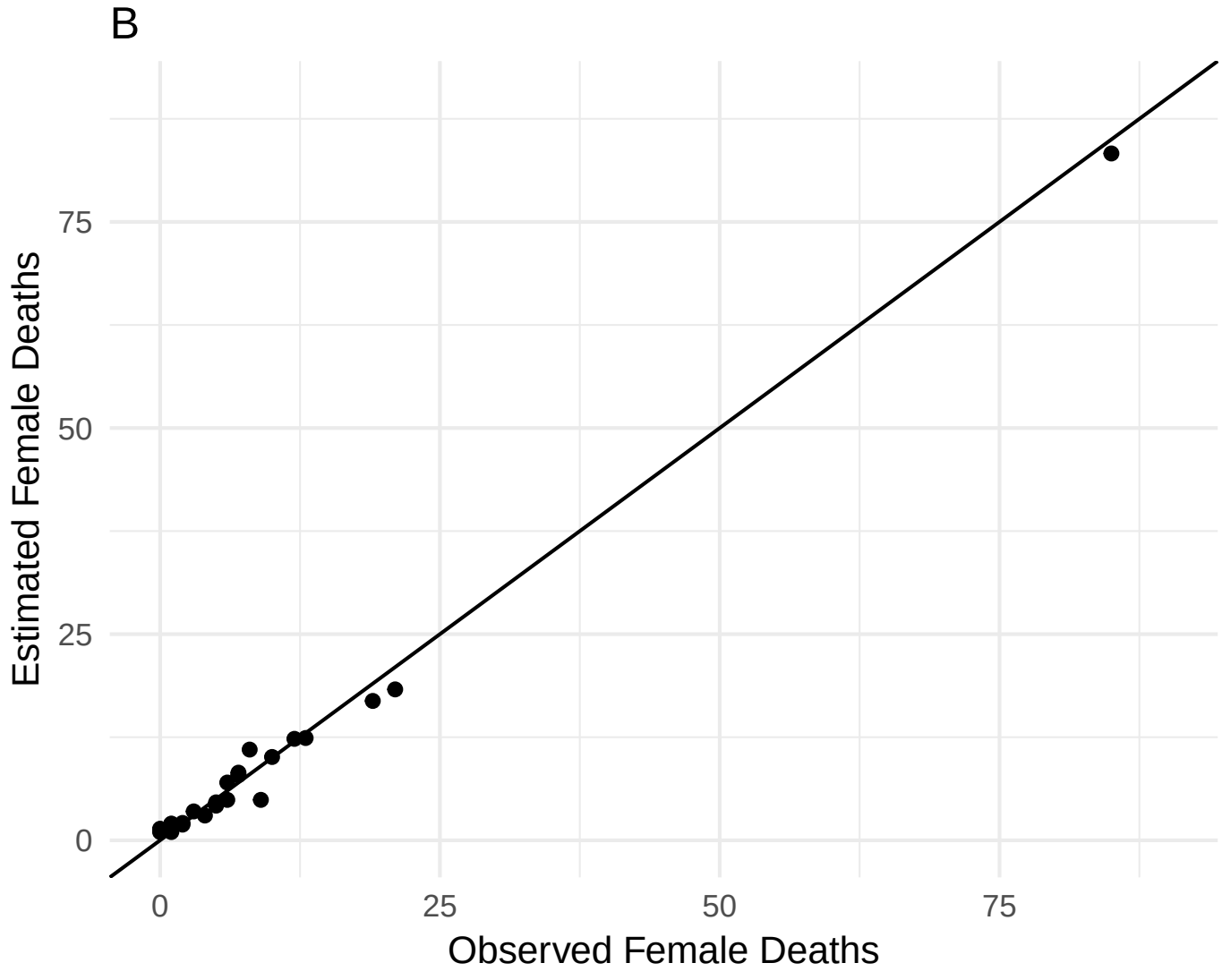
Tornado-Level Estimates

Date	State	Total Population	Male Population	Female Population
1995-01-07	FL	972	471	501
1995-05-18	TN	1598	772	826
1999-05-03	OK	24061	11808	12253
2005-11-06	KY	4046	1949	2097
2011-04-27	AL	33729	16346	17383
2011-05-22	MO	3461	1636	1825
2011-06-01	MA	25266	12304	12962
2015-12-26	TX	5738	2813	2925

Validation


A
Estimated Male Deaths
0
25
50
75
0
25
50
75
Observed Male Deaths

Validation


B
Estimated Female Deaths
0
25
50
75
0
25
50
75
Observed Female Deaths

Summary of Estimates

Variable	Mean	25^{th} Percentile	Median	75^{th} Percentile
Total Population	624	3.63	39.7	242
Population Density	132	6.23	17.5	57.2
Number of Males	303	1.80	19.7	119
Number of Females	321	1.85	19.9	122
White Population	421	2.92	31.4	189
Black Population	155	.020	.870	15.5
Household Median Income	$48,500	$38,700	$46,000	$55,400
Number of Mobile Homes	20.4	.168	2.11	11.9

Not shown: Population by age (under 17, 18-44, 45-64, and over 65)

Estimates: Total Population

Location/Tornado	Date	Number of Casualties	Total Population
Detroit, MI	1997-07-02	90	116167
St. Louis, MO	2013-05-31	8	46902
Pittsburgh, PA	1998-06-02	50	34802
Tuscaloosa–Birmingham, AL	2011-04-27	1564	33729
Springfield, MA	2011-06-01	203	25266
Bridge Creek–Moore, OK	1999-05-03	619	24062
St. Louis, MO	2011-04-22	5	22617
Minneapolis, MN	2011-05-22	49	22497
Nashville, TN	1998-04-16	61	20821
Hackleburg–Phil Campbell, AL	2011-04-27	217	20471

Estimates: Mobile Homes

Location/Tornado	Date	Number of Casualties	Mobile Homes
Hackleburg–Phil Campbell, AL	2011-04-27	217	1014
Vilonia, AR	2011-04-25	20	831
Shoal Creek Valley–Ohatchee, AL	2011-04-27	107	776
Cordova, AL	2011-04-27	67	721
Tuscaloosa–Birmingham, AL	2011-04-27	1564	718
Wichita, KS	2012-04-14	38	685
Bridge Creek–Moore, OK	1999-05-03	619	664
Auburn, AL	2011-11-16	4	604
Tallulah–Yazoo City–Durant, LA	2010-04-24	156	511
Little Rock, AR	1997-03-01	50	484

Estimates: Household Median Income

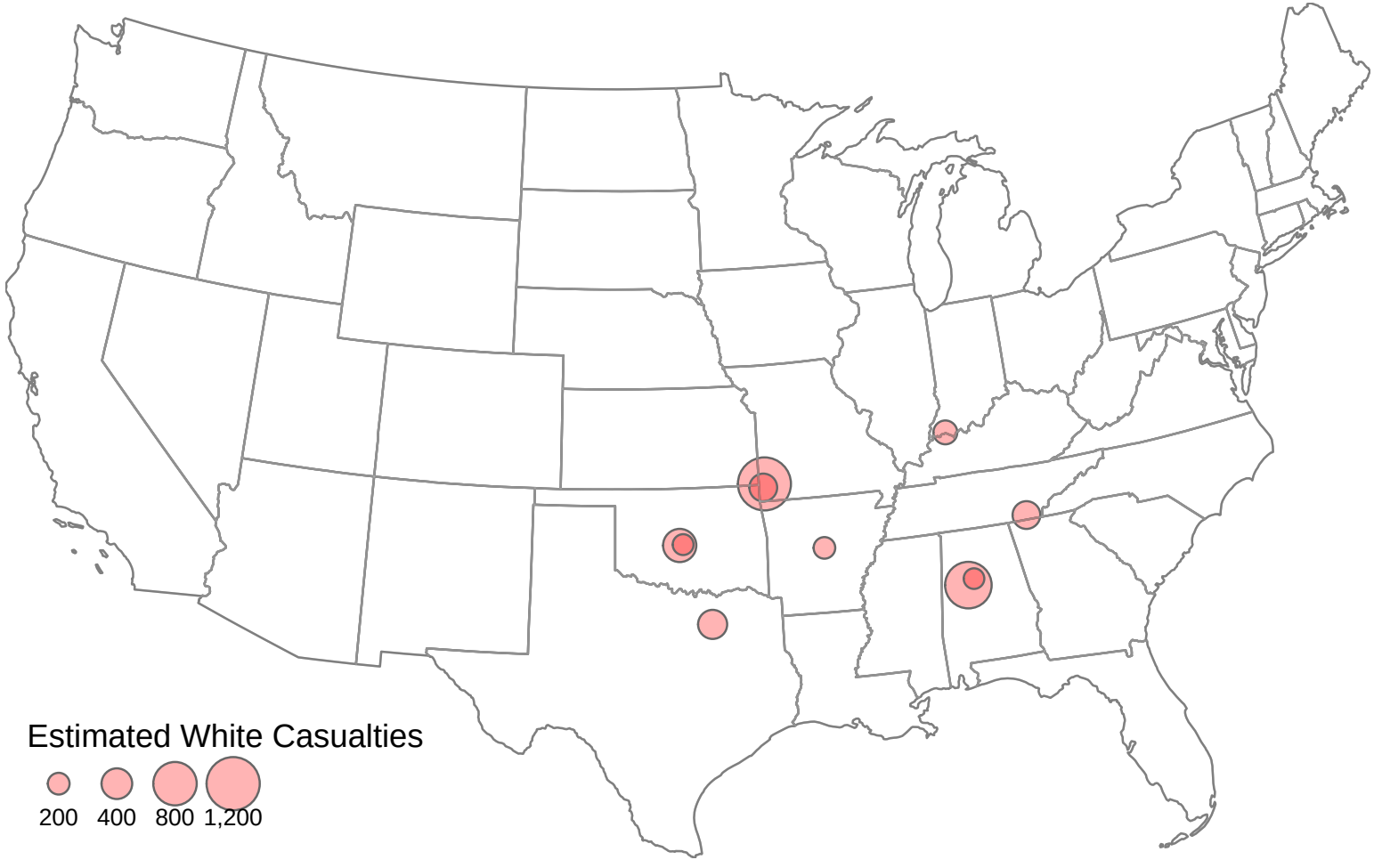
Location/Tornado	Date	Number of Casualties	Median Income
Denver, CO	2002-08-29	1	$161,152
Los Altos, CA	1998-05-05	1	$149,597
Fairfax, VA	1996-06-24	1	$139,458
Dunwoody, GA	1998-04-08	11	$119,549
Sonoma, CA	1996-12-23	1	$118,608
Westchester County, NY	2006-07-12	6	$117,882
Centreville, VA	2004-09-17	1	$116,493
Blue Ash, OH	1999-04-09	69	$115,559
Livingston-Genesee County, MI	2001-05-21	3	$114,426
Lake Travis, TX	1997-05-27	6	$112,936

Correlation Between Casualties and Estimates

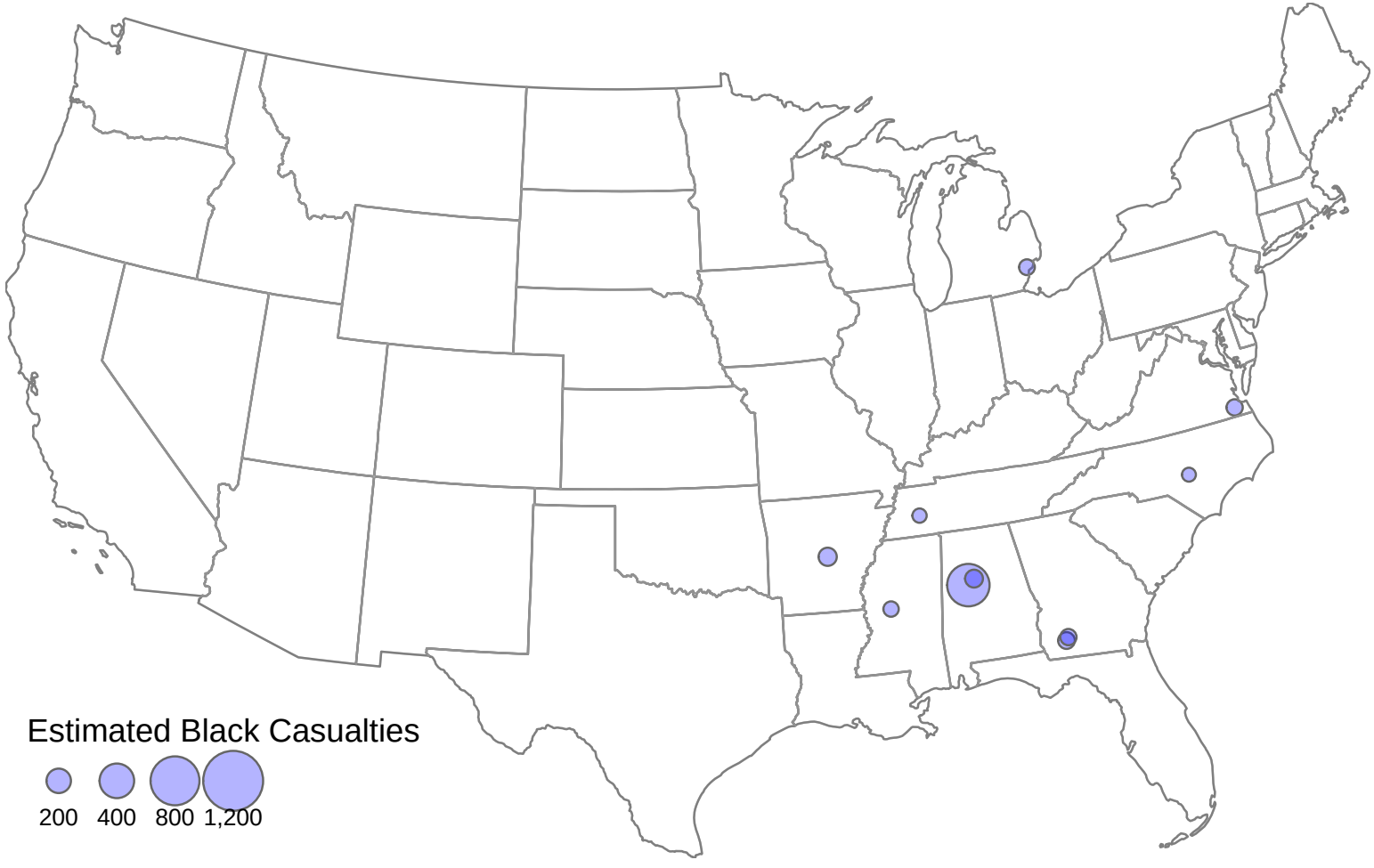
Variable	Correlation
Total Population	.33
Population Density	.02
Number of Males	.21
Number of Females	.20
White Population	.32
Black Population	.05
Household Median Income	.00
Number of Mobile Homes	.44

Not shown: Population by age (under 17, 18-44, 45-64, and over 65)

Estimated White Casualties by Tornado



Estimated Black Casualties by Tornado



Casualty Model

Estimates can be added to previous models (additive or interactive) to better understand the impact demographic and socioeconomic variables have on tornado casualties

Estimates of interest include:

- Young and old population
- White and black population
- Household median income
- Mobile homes

Casualty Model Results

- A 10 **mobile home** increase under the path **increases** the casualty rate by 4.2%
- A 100 person increase in the population **over 65** under the path **increases** the casualty rate by 1.4%
- A percentage increase in the **white** population under the path **decreases** the casualty rate by 25%

Casualty Model Results

- When controlling for the number of mobile homes, household median income IS NOT a significant factor
- Older populations (over 65) are a stronger predictor than younger populations (under 17)
- White populations are a stronger predictor than black populations

Future work

The casualty model will improve with more variables

Additional variables of interest include:

- Disability
- Educational attainment
- Ethnicity
- Language

Impact

Credit: NY Times

What questions do you have?

Addititve Model

The model is given by:

$$C \sim \text{NegBin}(\hat{\mu}, n) \quad (2)$$

$$\log(\hat{\mu}) = \hat{\alpha} \log(P) + \hat{\beta} \log(E) + \hat{\nu}, \quad (3)$$

where NegBin($\hat{\mu}$, n) indicates that the conditional casualty counts are described by negative binomial distributions with mean (rate) $\hat{\mu}$ and size n. The coefficient $\hat{\alpha}$ is the population elasticity, the coefficient $\hat{\beta}$ is the energy elasticity and $\hat{\nu}$ is the intercept parameter.

Interactive Model

The model is given by:

$$C \sim \text{NegBin}(\hat{\mu}, n) \tag{4}$$

$$\hat{\mu} = \hat{\beta}_0 \, P^{\hat{\beta}_P} \, E^{\hat{\beta}_E} \, (E \cdot P)^{\hat{\beta}_{P \cdot E}}, \tag{5}$$

where the coefficient $\hat{\beta}_P$ is the population elasticity, the coefficient $\hat{\beta}_E$ is the energy elasticity and $\hat{\beta}_{P \cdot E}$ is the interactive term.

Casualty Model

The casualty model is given by:

$$\log(\hat{C}) = \hat{\beta}_0 + \hat{\beta}_1 \log(P) + \hat{\beta}_2 \log(E) + \hat{\beta}_3 \log(P) \times \log(E) + \hat{\beta}_4 (V_1) + \hat{\beta}_5 (V_2) + \hat{\beta}_6 (V_3) + ... \tag{6}$$

where the coefficients $\hat{\beta}_1$, $\hat{\beta}_2$, and $\hat{\beta}_3$ are the population elasticity, energy elasticity, and interaction term, respectively. The coefficients $\hat{\beta}_4$, $\hat{\beta}_5$, and $\hat{\beta}_6$ are variable estimate terms, respectively.